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SEX DIFFERENCES IN ACCLIMATION TO A HOT-DRY ENVIRONMENT,(U)
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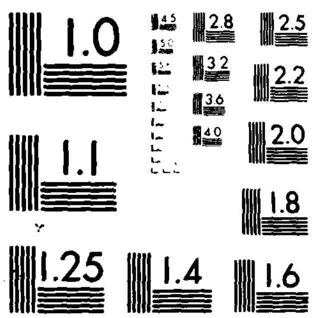

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Sex-related differences in acclimation to a hot-dry environment were evaluated in 10 males and 9 females. The subjects were exposed during early spring to a hot-dry climate: 49°C, 20% rh for 6 consecutive days. Exposure lasted 120 min: 10 min rest, 50 min walk (~~$1.34\ m \cdot s^{-1}$~~), 10 min rest, 50 min walk. Heart rate (HR), rectal temperature (T_{re}) mean skin temperature ($\bar{T}_{sk}$), and heat storage (~~ΔS~~) dropped significantly for both sexes (P<0.05), from the 1st to the 6th day with no significant changes (P>0.05) between the last two days. In spite of

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similar metabolism, similar sweat rate and lower heat gain by radiation and convection for the females, their T_{re} and $\bar{T}_{sk}$ remained significantly higher ($P<0.05$) than those of the males at the end of acclimation. It was suggested that the thermoregulatory set-point is higher for unacclimatized women than for men; this difference does not abolish with acclimation.

SEX DIFFERENCES IN ACCLIMATION TO A HOT-DRY ENVIRONMENT

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Running Head: Heat Acclimation of Men and Women

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Abstract

Sex-related differences in acclimation to a hot-dry environment were evaluated in 10 males and 9 females. The subjects were exposed during early spring to a hot-dry climate: 49°C, 20% rh for 6 consecutive days. Exposure lasted 120 min: 10 min rest, 50 min walk ($1.34\ m \cdot s^{-1}$), 10 min rest, 50 min walk. Heart rate (HR), rectal temperature (T_{re}) mean skin temperature ($\bar{T}_{sk}$), and heat storage (ΔS) dropped significantly for both sexes ($P < 0.05$), from the 1st to the 6th day with no significant changes ($P > 0.05$) between the last two days. In spite of similar metabolism, similar sweat rate and lower heat gain by radiation and convection for the females, their T_{re} and $\bar{T}_{sk}$ remained significant higher ($P < 0.05$) than those of the males at the end of acclimation. It was suggested that the thermoregulatory set-point is higher for unacclimatized women than for men; this difference does not abolish with acclimation.

1. Introduction

Acclimation is defined as "a physiological change, occurring within the life time of an organism, which reduces the strain caused by experimentally induced stressful changes in particular climatic factors" (Bligh and Johnson 1973). Acclimation to heat is characterized by a smaller rise in rectal temperature (T_{re}), mean skin temperature ($\bar{T}_{sk}$) and heart rate (HR), and therefore more effective and prolonged heat tolerance (Wyndham 1973). The main physiological mechanisms involved in acclimation are an earlier onset of sweating, greater sweat sensitivity (lower thermoregulatory set-point), and expanded plasma volume (Bonner et al. 1976, Wyndham 1973).

Many studies indicate that females acclimate to heat successfully, showing a similar pattern compared to men (Bar-Or et al. 1969, Cleland et al. 1969, Fein et al. 1975, Hertig et al. 1963, Nunneley 1978, Weinman et al. 1967, Wyndham et al. 1965), but despite this similarity some of these studies showed that the females achieved lower levels of acclimation (Cleland et al. 1969, Fein et al. 1975, Hertig et al. 1963) or a slower rate of acclimation (Wyndham et al. 1965). Bar-Or et al. (1969) showed no sex-related differences in acclimation, while Weinman et al. (1967) showed better acclimation for the females.

A recent study showed that while the basic thermal physiology for men and women is similar, the major sex differences are a higher surface to mass ratio for the females which helps them to dissipate heat both in hot-dry and hot-wet environments, and a higher thermoregulatory set-point under hot-dry conditions for the women (Shapiro et al. 1980). The later observation might raise questions as to whether this higher thermoregulatory set-point is a result of a lesser ability to reach a high level of acclimation, or whether a real sex difference exists in any state of heat acclimation regardless of the level of acclimation. The purpose of this study was to compare heat acclimation to hot-dry conditions between the sexes in terms of rate, level, heat balance and heat transfer.

2. Methods

Nine females and 10 males volunteer soldiers served as subjects. All subjects were totally informed with regard to experimental risk and gave their written informed consent. The physical characteristics of subjects are summarized in Table 1. All experiments were conducted during early spring while none of the subjects were exposed to environmental temperatures higher than 24°C for five months prior to the study.

INSERT TABLE 1 ABOUT HERE

Prior to the heat exposures, all subjects underwent medical examination, anthropometric measurements (height, weight, skinfold thickness) and determination of maximal oxygen uptake ($\dot{V}O_2$ max). Maximal oxygen uptake was determined from an intermittent treadmill running test utilizing methods and techniques modified from Taylor et al. (1955). During these tests, expired air was collected in Douglas bags; the volume was measured in a Collins Spirometer and converted to standard environmental conditions (STPD); and the O_2 and CO_2 concentrations were measured with an Applied Electrochemistry Model S-3A O_2 analyzer and Beckman LB-2 infrared CO_2 analyzer. Heart rate was calculated from R-R (ECG) intervals recorded on a Hewlett-Packard Model 1511A Electrocardiograph.

The nineteen male and female subjects, dressed in T-shirts, shorts, socks and indoor shoes, were then concurrently acclimated for 6 consecutive days by walking on a level motor-driven treadmill at $1.34\ m \cdot s^{-1}$ at $49^{o}C$, 20% rh, $1\ m \cdot s^{-1}$ wind speed. Each of these six exposures lasted 120 min: 10' rest, 50' walk, 10' rest, 50' walk. At the end of the first rest period and at the end of each walking period, two-minute expired air samples were collected in Douglas bags and analyzed as previously described for calculation of metabolic rate.

During all heat exposures, rectal temperature (T_{re}) was recorded from a Y.S.I. rectal thermistor probe inserted ~ 10 cm beyond the anal sphincter. Skin temperatures were monitored with a three-point thermocouple skin harness (chest, calf and forearm) and mean weighted skin temperature ($\bar{T}_{sk}$) was calculated according to Burton (1935). Using a Hewlett Packard 9825A Calculator and 9862A Plotter on-line during experimentation, both $\bar{T}_{sk}$ and T_{re} were plotted for each subject at approximately 2-min intervals. Heat storage (Δ S) was calculated as follows: $\Delta S = 0.965 (0.8\ \Delta T_{re} + 0.2\ \Delta \bar{T}_{sk})$ in $W \cdot kg^{-1} \cdot h^{-1}$. Heart rate was measured by radial artery palpation during the rest periods and after each 25 min of walking. Ad lib drinking was encouraged. Total body weight losses were determined from pre- and post-walk measurements on a K-120 Sauter precision electronic balance (accuracy of $\pm$ 10 g) for calculation of sweat rate. Sweat rate ($\dot{m}_{sw}$) was determined by loss of weight adjusted for: water intake, urine output, respiratory and metabolic weight losses Respiratory weight loss ($\dot{m}_e$) was calculated as: $\dot{m}_e = 0.019\ \dot{V}O_2\ (44 - P_a)$; $g \cdot min^{-1}$, and metabolic weight loss ($\dot{m}_r$) as: $\dot{m}_r = 0.53\ \dot{V}O_2$; $g \cdot min^{-1}$, where $\dot{V}O_2$ is the oxygen uptake in $l \cdot min^{-1}$ (STPD) and P_a is the ambient water pressure in mm Hg (Mitchell et al. 1972). The heat gain by radiation and convection (R + C) was determined according to Givoni et al. (1972). Sweat evaporative heat loss (E_{sw})

was calculated as: $E_{sw} = M + (R + C) - \Delta S - E_{res}$ where E_{res} is the respiratory heat loss calculated as $E_{res} = 0.0023\, M\, (44 - P_a)$ (Mitchell et al. 1972). The $\Delta\,(T_{re} - \bar{T}_{sk})$ was determined as an average value from each of the two minute values. Conductance (h_k) was determined as: $h_k = (M - \Delta S)/(T_{re} - \bar{T}_{sk})$; $W \cdot m^{-2} \cdot {}^{o}C^{-1}$ (Nadel 1972).

2.1 Statistical treatment.

Most variables were evaluated by use of a mixed design of two factors, with one factor being the two groups (male and female) and the other being the treatment (number of days in the heat) which both groups received. If a significant F-value was found ($P < 0.05$), critical differences were analyzed by Tukey's procedure to locate the significant mean differences.

3. Results

During the six days of heat acclimation, metabolism and $\dot{m}_{sw}$ remained unchanged and similar for both sexes. (see Figure 1 and Table 2).

INSERT FIGURE 1 ABOUT HERE

INSERT TABLE 2 ABOUT HERE

During acclimation, heart rate dropped 30.0 $b \cdot min^{-1}$ for males and 27.2 for the females ($P < 0.001$) as illustrated in Figure 2. Figure 3 shows that final T_{re}

dropped 0.46°C for the males and 0.70°C for the females ($P < 0.001$), while $\bar{T}_{sk}$ dropped 0.55°C for the females and 0.37°C for the males ($P < 0.005$) as presented in Table 2.

INSERT FIGURE 2 ABOUT HERE

INSERT FIGURE 3 ABOUT HERE

The heart rate showed a trend of higher values for the females than for the males, but this difference was not significant ($P > 0.05$). The T_{re} and $\bar{T}_{sk}$ which were significant higher for the woman remained significant higher after the heat acclimation period. The time change function for HR and T_{re} were found to be:

males: $T_{re} = 38.56 \exp(-0.003N)$, $r = 0.96$

$HR = 153.1 \exp(-0.005N)$, $r = 0.98$

females: $T_{re} = 39.02 \exp(-0.004N)$, $r = 0.98$

$HR = 161.7 \exp(-0.004N)$, $r = 0.96$

where: N is number of days in the heat.

No significant changes ($P > 0.05$) were found for T_{re}, $\bar{T}_{sk}$ or HR between the last two days of acclimation. The ΔS dropped significantly ($P < 0.01$) during acclimation for both sexes (0.06 $W \cdot kg^{-1}$ for the males and 0.37 for the females), but was not significantly different between sexes either before or after the acclimation (see Table 2). Heat gain by radiation and convection (R + C) as well as heat loss by evaporation of sweat (E_{sw}) were significantly higher ($P < 0.001$) for the males than for the females for all days, but did not change during acclimation.

Despite a higher $T_{re} - \bar{T}_{sk}$ gradient for the males (1.54 °C vs. 0.97 for females on the 1st day and 1.74 °C for males vs. 1.31 for females on the last day), similar conductance was found for both sexes both before and after acclimation. None of the changes mentioned were found to be correlated with maximal oxygen uptake ($\dot{V}O_2$ max).

4. Discussion

The subjects in this study were pre-exposed only to environmental temperatures below 24°C while the experimental temperature was 49°C. Thus, these subjects could be classified as unacclimated to the experimental conditions, such that their physiological reactions during the study could be considered as acclimation responses. It could also be suggested that the preacclimation conditions were relatively similar for both sexes.

The two major differences in terms of physical characteristics between males and females are the lower cardiorespiratory physical fitness for the females, and their smaller body size (lower weight, height and skin surface area; and higher surface to mass ratio). The importance of the later was discussed in a previous article (Shapiro et al. 1980) where it was shown that the body size, especially the surface area to mass ratio, played a major role in heat dissipation for females in hot-humid environments, but was not as important a factor in hot-dry environments. Lack of correlation between $\dot{V}O_2$ max and the thermoregulatory parameters found in this same study seemed to exclude the level of cardiorespiratory physical fitness as a major factor in the sex differences during acclimation.

Analyzing the T_{re}, $\bar{T}_{sk}$, Δ S and HR data illustrates that both sexes improved their thermoregulatory and cardiovascular responses during the acclimation. In contrast to Wyndham et al (1965) who suggested that females acclimate slower, the present study shows during acclimation that the rate of change was similar for both sexes ($e^{-0.003N}$ and $e^{-0.005N}$ for the males' T_{re} and HR; and, $e^{-0.004N}$ for the females' T_{re} and HR). These rates of change are in full agreement with those previously reported by Givoni et al. (1973) for other young male soldiers. All other heat balance and heat transfer parameters, i.e., M, R + C, E_{sw} and conductance remained as expected unchanged during acclimation, and as was previously shown by Shapiro et al. (1980), R + C, $\Delta(T_{re} - \bar{T}_{sk})$ and evaporative heat loss were lower for the women than for the men when values were expressed per unit body surface area.

In spite of similar rates of achieving heat acclimation, the final rectal temperature and mean skin temperature remained higher for the females after the acclimation as was also seen before acclimation. It is suggested that these differences are mainly due to a higher thermoregulatory set-point for the females as was found in other studies (Roberts et al. 1977, Shapiro et al. 1980) both before and after acclimation.

The literatur[illegible]troversy about the sex-related differences in acclimation can be explained by differences in environmental conditions to which the sexes have been acclimated and were tested before and after the acclimation. Weinman et al. (1967) showed that females acclimatized better than males in their study under hot-wet conditions which is an environment expected to result in better thermoregulatory reactions for females as shown by Shapiro et al.

(1980). However, Bar-Or et al. (1969) and Hertig et al. (1963) acclimated their subjects to hot-dry conditions, and found higher post-acclimation T_{re} and/or $\bar{T}_{sk}$ responses for the females as was confirmed in the present study. Roberts et al. (1977) who acclimated their subjects to a hot-wet environment, but tested them both pre and post-acclimation in mild conditions (25^{o}C), showed the existence of differences in thermoregulatory set-point regardless of acclimation and physical training.

It can be concluded that males and females acclimated to a hot-dry environment at the same rate. The females' post-acclimatization thermoregulatory set-point remained higher than the males' similar to the sex-related differences seen in the pre-acclimatization phase. The pre-acclimation sex differences in heat balance and heat transfer (lower R + C, E_{sw} and $\Delta(T_{re} - \bar{T}_{sk})$ for the women) are not altered by the acclimation process.

1. The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

2. Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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Table 1. Physical characteristics of the subjects.

	Males			Females		
Number of subjects		10			9	
Age (yr)	21.1	$\pm$	0.6	22.0	$\pm$	1.0
Height (cm)	178.6	$\pm$	2.1	161.5	$\pm$	2.3
Weight (kg)	75.6	$\pm$	4.2	56.6	$\pm$	2.6
Body fat (%)	17.7	$\pm$	1.6	29.6	$\pm$	1.5
Skin surface area (m^2)	1.93	$\pm$	0.06	1.59	$\pm$	0.04
$\dot{V}O_2$ max ($mmol \cdot kg^{-1} \cdot min^{-1}$)	2.33	$\pm$	0.10	1.81	$\pm$	0.07
($\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$)	52.3	$\pm$	2.2	40.5	$\pm$	1.5)

Values are mean $\pm$ SE.

(The results in brackets from the last line of the table are in the traditional units of $ml \cdot kg^{-1} \cdot min^{-1}$).

Table 2. Differences in thermoregulation between males (M) and females (F) during the 1st day (1st) and 6th day (6th) of heat acclimation.

	1st day		6th day		P	P
	M	F	M	F	M vs F	1st vs 6th
Final T_{re}, °C	38.40 ± 0.09	38.89 ± 0.12	37.94 ± 0.08	38.19 ± 0.07	0.005	0.001
Final HR, b min^{-1}	147.0 ± 15.0	157.3 ± 9.1	117.0 ± 10.8	130.1 ± 4.6	N•S	0.001
T_{sk}, °C	36.30 ± 0.15	36.99 ± 0.22	35.93 ± 0.14	36.44 ± 0.14	0.01	0.005
$\dot{m}_{sw}$, $g{\cdot}m^{-2}{\cdot}h^{-1}$	446.5 ± 15.0	447.7 ± 17.5	470.7 ± 18.6	436.1 ± 14.9	N•S	N•S
M, $W \cdot kg^{-1}$	5.21 ± 0.10	5.03 ± 0.10	5.00 ± 0.14	5.00 ± 0.10	N•S	N•S
ΔS, $W{\cdot}kg^{-1}$	0.62 ± 0.08	0.94 ± 0.10	0.56 ± 0.06	0.57 ± 0.06	N•S	0.01
R + C, $W{\cdot}m^{-2}$	132.2 ± 2.2	121.0 ± 1.3	127.6 ± 3.0	122.8 ± 2.2	0.001	N•S
E_{sw}, $W{\cdot}m^{-2}$	277.7 ± 3.5	237.3 ± 4.4	276.8 ± 6.4	254.4 ± 6.4	0.001	N•S
$\Delta(T_{re}-T_{sk})$, °C	1.54 ± 0.17	0.97 ± 2.22	1.74 ± 0.18	1.31 ± 0.19	0.05	N•S
h_k, $W{\cdot}m^{-2}{\cdot}{}^{o}C^{-1}$	115.8 ± 17.3	116.4 ± 10.9	107.1 ± 10.5	105.2 ± 11.8	N•S	N•S

Values are means ± SE.

Figure Legends

Figure 1. Sweat rate during six days of heat acclimation for the males (solid line), and the females (dashed line) presented on $g \cdot kg^{-1} \cdot h^{-1}$ and $g \cdot m^{-2} \cdot h^{-1}$.

Figure 2. Final heart rate ($b \cdot min^{-1}$) during the six days of acclimation for the males (solid line) and the females (dashed line).

Figure 3. Final rectal temperature (^{o}C) during the six days of acclimation for the males (solid line) and the females (dashed line).

Fig 1

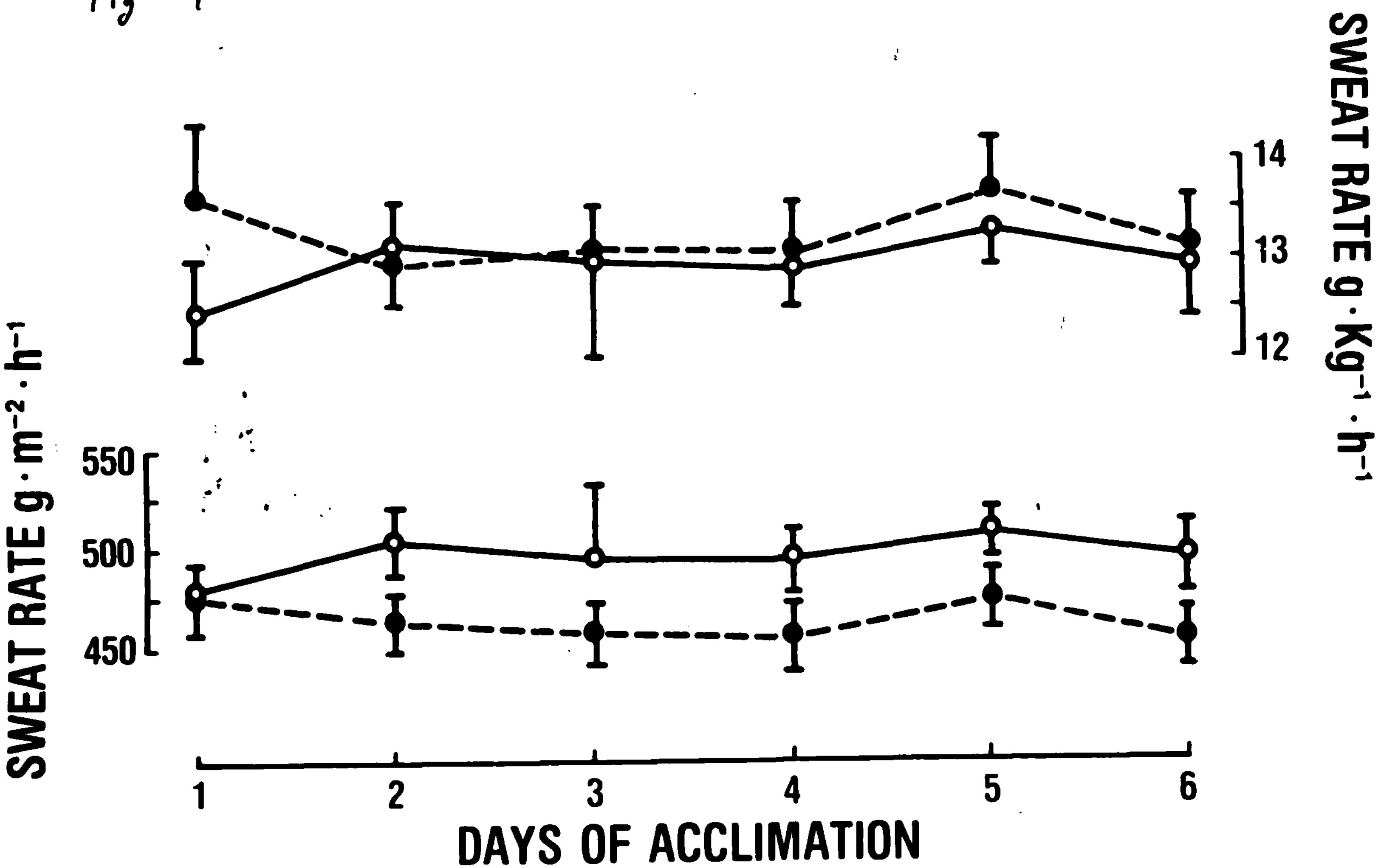
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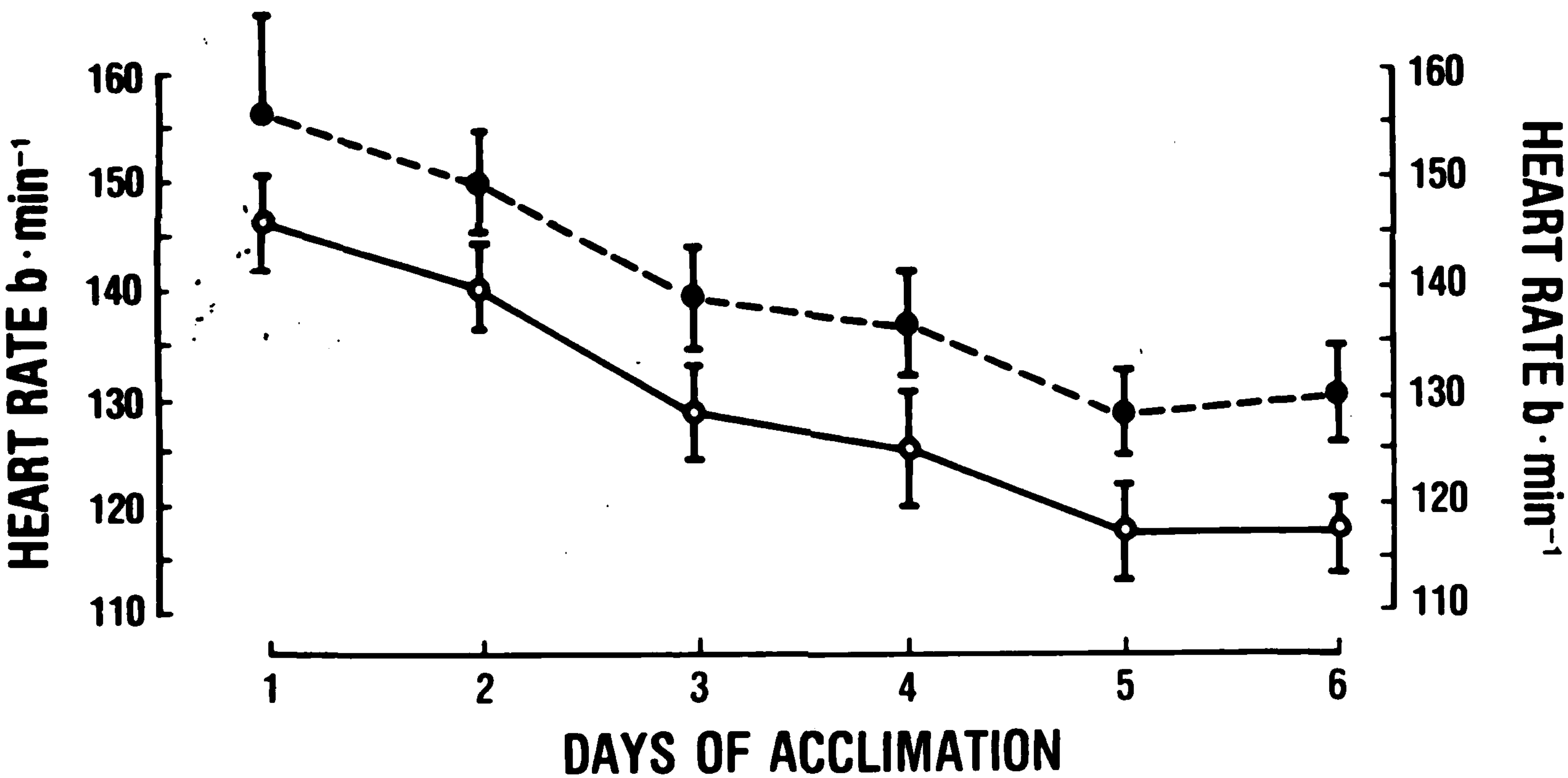
Fig 2



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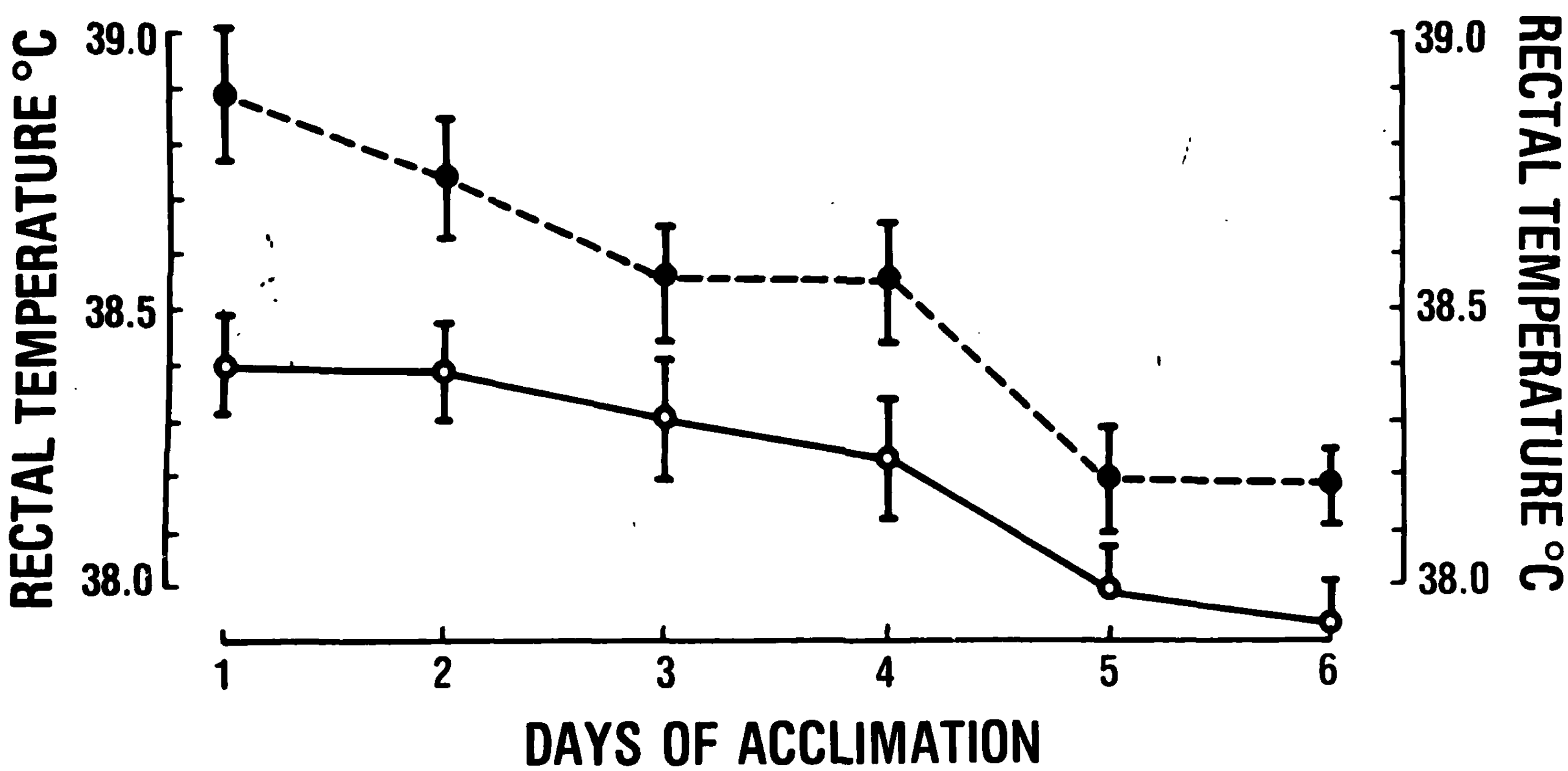
DAYS OF ACCLIMATION

Fig 3



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